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## *The Effects of Tympanic Membrane Intubation on Middle Ear Resonant Frequency in Children*

### *Les effets de l'intubation de la membrane tympanique sur la fréquence de résonance de l'oreille moyenne chez les enfants*

by • par

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#### ABSTRACT

The long term effects of otitis media with effusion (OME) and tympanic membrane intubation on middle ear function were investigated using multifrequency tympanometry. Children, aged 4;4 (years;months) to 13;1, with a history of OME and intubation comprised the experimental group (19 ears). Normal-hearing children, aged 6;0 to 11;11, with a reported negative history of otitis media and intubation served as the control group (26 ears). Middle ear resonant frequency for both groups of children was assessed with multifrequency tympanometry. There was no significant difference in middle ear resonant frequency values between the two groups of children. In addition, the resonant frequency values of the experimental group exhibited substantial overlap with previously published normative data. These findings support the conclusion that the resonant frequency measure is relatively immune to nonpathologic tympanic membrane and middle ear alterations in children with a history of OME and intubation, as these children do not present with abnormal resonant frequency measures.

#### ABRÉGÉ

Les effets à long terme de l'otite moyenne suppurée (OMS) et de l'intubation de la membrane tympanique sur la fonction de l'oreille moyenne ont été étudiés au moyen de la tympanométrie multifréquence. Des enfants âgés de 4;4 (ans;mois) à 13;1, avec antécédents d'OMS et d'intubation, ont composé le groupe expérimental (19 oreilles). Des enfants à audition normale, âgés de 6;0 à 11;11, sans antécédents d'otite moyenne ou d'intubation, ont servi de groupe témoin (26 oreilles). La fréquence de résonance de l'oreille moyenne des deux groupes d'enfants a été étudiée par tympanométrie multifréquence. On n'a relevé aucune différence significative pour ce qui est des valeurs de fréquence de résonance de l'oreille moyenne chez les deux groupes d'enfants. De plus, les valeurs de fréquence de résonance du groupe expérimental ont fait état d'un important recouvrement par rapport aux données normatives publiées antérieurement. Ces conclusions confirment donc que la mesure de la fréquence de résonance est relativement peu influencée par les altérations non pathologiques de la membrane tympanique et de l'oreille moyenne chez les enfants avec antécédents d'OMS et d'intubation car ces enfants ne présentent aucune mesure anormale de fréquence de résonance.

#### KEY WORDS

tympanic membrane intubation • multifrequency tympanometry • otitis media • resonant frequency

The use of multifrequency tympanometry as a clinical procedure was first reported by Colletti (1976). This technique provides acoustic immitance measures of the middle ear using probe tones ranging in frequency from 200 Hz to 2000 Hz. Multifrequency tympanometry also provides an estimate of the resonant frequency of the middle ear system. This measure is important for differentiating pathologies that lower resonant frequency (e.g., ossicular discontinuity and monomeric tympanic membrane) from those which raise resonant frequency (e.g., ossicular fixation, Hunter & Margolis, 1992).

The tympanometric model suggested by Vanhuysse, Creten, and Van Camp (1975) is central to the application of multi-

frequency tympanometry in clinical populations. In this model, four tympanometric patterns are derived from the interaction of resistance and reactance in normal ears. As probe tone frequency increases, tympanometric patterns change from the familiar 226 Hz single notched pattern to other normal patterns characterized by multiple peaks for both conductance and susceptance tympanograms. In normal ears, typical patterns are present at specific ranges of probe frequencies. Abnormal ears, on the other hand, are characterized by patterns not consistent with the Vanhuysse model, and may show middle ear resonant frequencies above or below the normal range (Margolis, Hunter, & Giebink, 1994).



At the present time, multifrequency tympanometry does not enjoy widespread clinical use presumably due to the time required to complete the procedure (Hunter & Margolis, 1992). New microprocessor-based acoustic immittance devices now have the capability to perform multifrequency measures in a timely and usable fashion. Normative data have been reported for adults (Margolis & Goycoolea, 1993), children (Hunter & Margolis, 1992; Maso & Wiley, 1990), and the elderly (Holte, 1996).

Multifrequency tympanometry has been suggested as a test procedure to provide information concerning otitis media with effusion (OME) in young children (Margolis et al., 1994). Specifically, it can be applied in monitoring OME because the procedure is more sensitive to ongoing mechanical disturbances than conventional (i.e., 226 Hz probe) tympanometry (Hunter & Margolis, 1992). Further, Margolis et al. (1994) reported that some children with normal hearing and a history of OME and intubation may have abnormal resonant frequencies. Their results indicated that approximately one third of these children had abnormal multifrequency tympanometric findings, despite the fact that they no longer had pathological middle ear conditions. Abnormal findings included unclassifiable patterns, and abnormally low and high resonant frequencies. These findings demonstrated that multifrequency tympanometry had the capability to detect some alterations in the middle ear mechanism not evident with conventional single probe tympanometry.

The purpose of the present study was to investigate the long term effects of OME and tympanic membrane intubation on middle ear resonant frequency in children, as compared to normal hearing children who exhibited an absence of a significant history of otitis media and intubation. Further, it was proposed that inclusion of otoscopic information may complement the value of resonant frequency findings in children with histories of OME and intubation.

## Method

### Participants

In this study, participants in the experimental group (six males and six females) had a history of resolved OME and tympanic membrane intubation and ranged in age from 4;4 (years;months) to 13;1 ( $M = 9.3$  years,  $SD = 2.6$  years). Data were obtained from 19 ears for this group. The control group consisted of five males and nine females, ranging in age from 6;0 to 11;11 ( $M = 9.5$  years,  $SD = 1.5$  years). Data were obtained for 26 ears in the control group. Children in the experimental group were all Caucasians, while the control group consisted of five African-Canadians<sup>1</sup> and nine Caucasians. Participants in the control group had essentially a negative history of OME (i.e., not more than two episodes of OME) and no history of tympanic membrane perforation and/or pressure equalization (PE) tubes as established from

parental reports. All participants in this study were volunteers.

All participants in the control group were classified as having normal middle ear mechanisms according to clinical guidelines established by Silman, Silverman, and Arick (1992) and the American Speech-Language-Hearing Association (1990). That is, all participants presented with the absence of middle ear abnormality as judged by: (a) visual inspection of outer ear, head, and neck; (b) otoscopic inspection of the ear canal and eardrum by a paediatric otolaryngologist; (c) normal 226 Hz acoustic admittance ( $Y_a$ ) tympanogram; and, (d) presence of ipsilateral acoustic reflexes for the ear under consideration at 500 Hz and 1000 Hz. Inclusion criteria were identical for the experimental group, except the 226 Hz admittance ( $Y_a$ ) tympanograms were considered normal if they were single peaked (i.e., no restrictions were made on  $Y_a$  values that exceeded guidelines recommended by the American Speech-Language-Hearing Association, 1990).

### Apparatus

Hearing screening was conducted using audiometers that were calibrated to published standards (American National Standards Institute, 1996). All acoustic immittance data (i.e., 226 Hz admittance tympanogram, ipsilateral acoustic reflexes, and multifrequency measurements) were obtained with a middle-ear analyzer (Grason-Stadler Model GSI 33 Version 2) calibrated to comply with the published standards on aural acoustic immittance instruments (American National Standards Institute, 1987). Calibration was conducted prior to the start of data collection and checked at the conclusion of the study. In addition, biological calibration of all audiological/acoustic immittance equipment was carried out before each test session. The 226 Hz tympanogram was obtained using a pump speed of 200 daPa/s. Static acoustic admittance measurements were obtained by subtracting the acoustic admittance measurement obtained at the + 200 daPa "tail" from the "peak" acoustic admittance.

The GSI 33 Version 2 immittance device performs multifrequency tests using the "frequency sweep" method. Initially, a 226 Hz tympanogram is obtained. Then the device conducts automated frequency sweeps from 250 Hz to 2000 Hz at + 200 daPa, followed by a similar frequency sweep at a pressure corresponding to the tympanometric peak pressure measured from the 226 Hz probe measurement. The frequency sweeps are conducted in 50 Hz steps while the instrument simultaneously stores the changes in susceptance ( $B_a$ ) in memory. Finally, the acoustic immittance device records resonant frequency of the middle ear at the probe frequency which produces a susceptance ( $B_a$ ) at peak pressure that is equal to or less than the susceptance ( $B_a$ ) value measured at + 200 daPa.

### Procedure

For each participant, a hearing screening (using standard audiometry or play audiometry procedures), a middle ear assessment that included multifrequency tympanometry, and

otoscopic examination were obtained in a single session. At the time of testing, the attending otolaryngologist examined the tympanic membrane using otoscopy and pneumatoscopy. The state of the tympanic membrane of each participant was characterized by one of a set of diagnostic options designated by the otolaryngologist. These options included the following subgroups: (a) a normal tympanic membrane (TM), (b) monomeric TM, (c) tympanosclerotic TM, and (d) the presence of a graft (i.e., tympanoplasty or myringoplasty). For each ear tested, two consecutive measurements of resonant frequency were obtained without removing the probe of the middle ear analyzer. The data from the second test run were used to establish an estimate of the test-retest consistency.

## Results

### Test-retest Analyses

Test and retest resonant frequency values were obtained from 26 and 19 ears of the control and experimental groups, respectively. Exclusion of ears from the control group was due to inability to obtain a hermetic seal and exclusion from the experimental group was on the basis of lack of a seal and/or no history of intubation. Differences between test and retest measures were within 100 Hz (only two 50 Hz increments of the immittance device) with the exception of three ears where test-retest values differed as much as 200 Hz. Test-retest variability was assessed with correlational analyses. The Pearson Product Moment correlation between test and retest values collapsed across groups was found to be high ( $r = .891$ ;  $p < .0001$ ). As well, high positive Pearson Product Moment correlations were found with the separate control ( $r = .853$ ;  $p < .0001$ ) and experimental ( $r = .932$ ;  $p < .0001$ ) test-retest values. Since correlation analyses only provide information concerning the covariation of the groups, further statistical analyses were conducted to investigate test-retest variability.

Separate paired *t*-tests were used to compare differences between the mean test and retest resonant frequency measurements for the control and experimental groups. No significant differences in mean test and retest resonant frequency were noted for either the control ( $t[25] = 1.259$ ;  $p = .2196$ ) or the experimental ( $t[18] = -.411$ ;  $p = .6861$ ) group. The 95% lower and upper confidence intervals for the control and experimental group were -16 to 66 Hz and -48 to 33 Hz, respectively.

### Resonant Frequency Analyses

The initial test values were used in the analysis of group differences in resonant frequency (see Figure 1). The mean middle ear resonant frequencies were 985 Hz ( $SD = 194$ ) and 1003 Hz ( $SD = 1229$ ) for the control and experimental groups, respectively. An independent *t*-test indicated no

**Table 1. Resonant Frequency Means and 90% Ranges for the Tympanic Membrane (TM) Based Subgroupings.**

	Normative Data <sup>1</sup>	Control n=26	Experimental Subgroups		
			Normal TM n=7	Monomeric TM n=5	Tympanosclerotic TM n=5
Resonant Frequency					
Mean	1211Hz	985	1107	1107	1090
90% Range	800-1800	763-1410	922-1330	638-1310	922-1330

*Note.* 1. The normative data are taken from Hunter and Margolis (1992). Data obtained for the graft experimental subgroup are not included due to small sample size ( $n = 2$ ).

significant differences between these measurements ( $t[43] = -.285$ ,  $p = 0.777$ ). As comparisons of central tendency between measures may not be an accurate indication of the variability across groups, an analysis of the variance in resonant frequencies between groups was undertaken. This analysis indicated that there was not a significant difference in resonant frequency variance between the two groups ( $F[25,18] = .714$ ;  $p = .447$ ).

A descriptive analysis of the resonant frequency values for the control group and the otoscopic observations from the experimental group are contained in Table 1. Normative data from Hunter and Margolis (1992) are also included for comparison. Both groups of children investigated in the present study fell within the 90% range of the Hunter and Margolis norms. The subgrouping of the target group by otoscopy indicated resonant frequency values consistent with what would be expected from the physical alterations to the tympanic membrane. That is, children with tympanosclerotic tympanic membranes were consistently higher than the mean of the control group and the Hunter and Margolis norms while children with monomeric eardrums exhibited lower resonant frequency values.

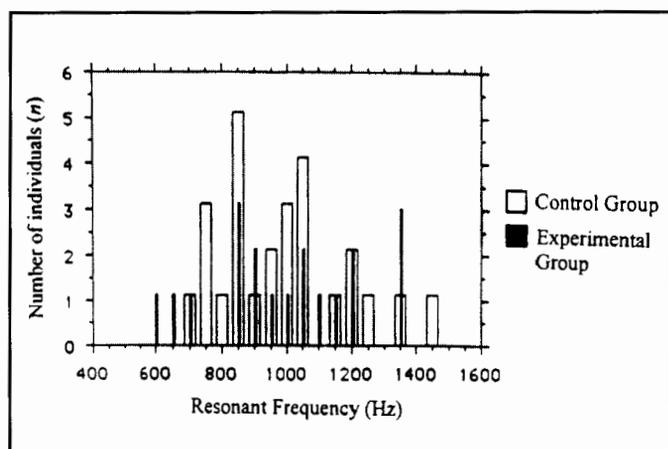
## Discussion

The diagnostic value of multifrequency tympanometry, specifically, the resonant frequency of the middle ear, is determined by the relative mass and stiffness contributions to the middle ear mechanism. As a result, mass loading or a decrease in stiffness in the middle ear causes a lowering of the resonant frequency from normal values. In addition, an abnormal increase in the stiffness of the middle ear will cause an increase in the resonant frequency compared to normal resonant frequency values (Shanks & Shelton, 1991). The aim of this study was to determine if a history of tympanic membrane intubation affects middle ear resonant frequency in children.



An examination of the mean resonant frequency values revealed no statistically significant differences between children with a history of OME and intubation and those with a negative history of such a condition (see Figure 1). This finding would indicate that a history of tympanic membrane intubation does not significantly alter the mass or stiffness contribution to sound transmission in the middle ear. An alternative explanation would be that both mass and stiffness are altered to a similar degree, and thus these alterations fail to produce a deviation in the resonant frequency relative to normal middle ear function.

**Figure 1. Frequency distribution of middle ear resonant frequencies in the experimental and control groups.**



Margolis et al. (1994) reported that 63% of 98 children with a history of otitis media and PE tubes presented with normal multifrequency tympanograms. At the time of testing, these children showed normal hearing sensitivity, normal 226 Hz tympanograms, and no evidence of active ear disease on visual inspection. Eleven percent of participants displayed low middle ear resonant frequencies, while the remaining 26% had irregular patterns not predicted by the Vanhuyse model. In the present study, only three ears (16%) of the experimental group presented with resonant frequencies beyond the 90% range for normal ears. Of these, the middle ear resonant frequency of the ear with an unspecified graft (i.e., myringoplasty or tympanoplasty) was 650 Hz, while the resonant frequencies of the two ears that presented with monomeric tympanic membranes were 700 Hz and 600 Hz respectively. The findings of this study were consistent with those of Margolis et al. (1994): children with histories of OME and tympanic membrane intubation, in most cases, present with normal middle ear function as assessed by multifrequency tympanometry. Both studies also confirm that a small number of ears from these children show lower extreme values for middle ear resonant frequency.

There is a discrepancy, however, between the present findings and those of Margolis et al. (1994), in terms of the proportion of abnormal multifrequency tympanometry findings in children with OME and intubation (cf. 16% vs. 37%). This discrepancy may be due primarily to a difference in the multifrequency tympanometry measurements examined, and to a lesser extent, to differences in sample sizes and acoustic immittance equipment used. Margolis et al. explored both the resonant frequency and multifrequency tympanogram configurations, whereas the present study examined only resonant frequency measurements. This comparison may indicate that middle ear assessment using both resonant frequency and the Vanhuyse configurations for normal tympanograms is more sensitive to subtle mechanical changes in the middle ear than resonant frequency alone. Stated another way, the resonant frequency measure on its own may be relatively immune to nonpathologic middle ear alterations in children with histories of OME and PE tube placement. It may well be worthwhile to investigate the clinical efficiency of using both measures rather than resonant frequency alone.

An examination of the experimental subgroups' mean resonant frequency values revealed small differences relative to the control group. The mean resonant frequency of middle ears with tympanosclerosis was slightly greater than the mean for normal ears (see Table 1), which may indicate that this tympanic membrane alteration is associated with a small stiffness increase. A similar small "stiffening effect" was observed in the middle ears of children in the experimental subgroup with normal tympanic membranes (i.e., healed perforations that were free of tympanosclerosis and monomeric conditions). The middle ears of these individuals presented with a mean resonant frequency that was slightly elevated when compared to the mean of normal ears. In addition, the group with monomeric tympanic membranes had a mean resonant frequency that was slightly lower than that of the control group (see Table 1). This may indicate a small "mass effect" in the middle ears of these participants. No studies were found, apart from this one, which had analyzed the resonant frequency distributions that are associated with different tympanic membrane alteration. One should note, however, that the above-mentioned analyses are descriptive and based on a small sample of observations.

In summary, the data obtained from this study indicate that the resonant frequency measure may be immune to minor aberrations that could be associated with OME and tympanic membrane intubation histories. These tympanic membrane alterations, confirmed by otoscopy, represent conditions that influence both the mass and stiffness characteristics of the middle ear. The effects of these sequelae are minimal when compared to normal. That is, the changes to resonant frequency may not be distinguished from normal, presumably due to the wide range of stiffness/mass interactions found in normal ears. These observations warrant the conclusion that

tympanic membrane and middle ear changes following OME and surgically controlled perforation, do not appear to contribute to an abnormal resonant frequency measurement. In clinical diagnosis, the interpretation of an abnormal resonant frequency finding in a child with a history of OME and intubation may necessitate closer examination of other factors as potential contributors to an abnormal result.

#### Endnote

1. Consideration was given to the findings of Roush, Bryant, Mundy, Zeisel, and Roberts (1995) concerning the possible age and race effect of lower static compliance for infants and toddlers of African-American origin. The five participants of African-Canadian origin in the control group did not appear to generate test data that were in contrast to any other children in the group.

#### Author Notes

The first author is currently affiliated with The S. A. Grace General Hospital, St. John's, NFLD. This paper is based on a research project completed while the first author was a graduate student at Dalhousie University. Portions of this paper were presented at the Canadian Association of Speech-Language Pathologists and Audiologists Conference, Toronto, Ontario, May, 1997. The authors would like to thank Michel Comeau and Gordon Whitehead of the Nova Scotia Hearing and Speech Clinic for their support and use of their clinical facilities. Special gratitude is extended to Dr. Andrew Stuart for his suggestions and comments.

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